AD NO. ____________________

DTC PROJECT NO. 8-CO-160-UXO-021

REPORT NO. ATC-9110

STANDARDIZED

UXO TECHNOLOGY DEMONSTRATION SITE

BLIND GRID SCORING RECORD NO. 293

SITE LOCATION:
U.S. ARMY YUMA PROVING GROUND

DEMONSTRATOR:
GEO-CENTERS, INC.
7 WELLS AVENUE
NEWTON, MA 02459

TECHNOLOGY TYPE/PLATFORM:
SIMULTANEOUS MULTI-SENSOR SURFACE
TOWED ORDNANCE LOCATION
SYSTEM (STOLS)/TOWED ARRAY

PREPARED BY:
U.S. ARMY ABERDEEN TEST CENTER
ABERDEEN PROVING GROUND, MD 21005-5059

OCTOBER 2005

Prepared for:
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14. ABSTRACT
This scoring record documents the efforts of GEO-CENTERS, Inc., to detect and discriminate inert unexploded ordnance (UXO) utilizing the YPG Standardized UXO Technology Demonstration Site Blind Grid. Scoring Records have been coordinated by Larry Overbay and the Standardized UXO Technology Demonstration Site Scoring Committee. Organizations on the committee include, the U.S. Army Corps of Engineers, the Environmental Security Technology Certification Program, the Strategic Environmental Research and Development Program, the Institute for Defense Analysis, the U.S. Army Environmental Center, and the U.S. Army Aberdeen Test Center.

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1.1 BACKGROUND

Technologies under development for the detection and discrimination of unexploded ordnance (UXO) require testing so that their performance can be characterized. To that end, Standardized Test Sites have been developed at Aberdeen Proving Ground (APG), Maryland and U.S. Army Yuma Proving Ground (YPG), Arizona. These test sites provide a diversity of geology, climate, terrain, and weather as well as diversity in ordnance and clutter. Testing at these sites is independently administered and analyzed by the government for the purposes of characterizing technologies, tracking performance with system development, comparing performance of different systems, and comparing performance in different environments.

The Standardized UXO Technology Demonstration Site Program is a multi-agency program spearheaded by the U.S. Army Environmental Center (AEC). The U.S. Army Aberdeen Test Center (ATC) and the U.S. Army Corps of Engineers Engineering Research and Development Center (ERDC) provide programmatic support. The program is being funded and supported by the Environmental Security Technology Certification Program (ESTCP), the Strategic Environmental Research and Development Program (SERDP) and the Army Environmental Quality Technology Program (EQT).

1.2 SCORING OBJECTIVES

The objective in the Standardized UXO Technology Demonstration Site Program is to evaluate the detection and discrimination capabilities of a given technology under various field and soil conditions. Inert munitions and clutter items are positioned in various orientations and depths in the ground.

The evaluation objectives are as follows:

a. To determine detection and discrimination effectiveness under realistic scenarios that vary targets, geology, clutter, topography, and vegetation.

b. To determine cost, time, and manpower requirements to operate the technology.

c. To determine demonstrator's ability to analyze survey data in a timely manner and provide prioritized "Target Lists" with associated confidence levels.

d. To provide independent site management to enable the collection of high quality, ground-truth, geo-referenced data for post-demonstration analysis.

1.2.1 <u>Scoring Methodology</u>

a. The scoring of the demonstrator's performance is conducted in two stages. These two stages are termed the RESPONSE STAGE and DISCRIMINATION STAGE. For both stages, the probability of detection (P_d) and the false alarms are reported as receiver-operating

characteristic (ROC) curves. False alarms are divided into those anomalies that correspond to emplaced clutter items, measuring the probability of false positive (P_{fp}), and those that do not correspond to any known item, termed background alarms.

b. The RESPONSE STAGE scoring evaluates the ability of the system to detect emplaced targets without regard to ability to discriminate ordnance from other anomalies. For the blind grid RESPONSE STAGE, the demonstrator provides the scoring committee with a target response from each and every grid square along with a noise level below which target responses are deemed insufficient to warrant further investigation. This list is generated with minimal processing and, since a value is provided for every grid square, will include signals both above and below the system noise level.

c. The DISCRIMINATION STAGE evaluates the demonstrator's ability to correctly identify ordnance as such and to reject clutter. For the blind grid DISCRIMINATION STAGE, the demonstrator provides the scoring committee with the output of the algorithms applied in the discrimination-stage processing for each grid square. The values in this list are prioritized based on the demonstrator's determination that a grid square is likely to contain ordnance. Thus, higher output values are indicative of higher confidence that an ordnance item is present at the specified location. For digital signal processing, priority ranking is based on algorithm output. For other discrimination approaches, priority ranking is based on human (subjective) judgment. The demonstrator also specifies the threshold in the prioritized ranking that provides optimum performance, (i.e. that is expected to retain all detected ordnance and rejects the maximum amount of clutter).

d. The demonstrator is also scored on EFFICIENCY and REJECTION RATIO, which measures the effectiveness of the discrimination stage processing. The goal of discrimination is to retain the greatest number of ordnance detections from the anomaly list, while rejecting the maximum number of anomalies arising from non-ordnance items. EFFICIENCY measures the fraction of detected ordnance retained after discrimination, while the REJECTION RATIO measures the fraction of false alarms rejected. Both measures are defined relative to performance at the demonstrator-supplied level below which all responses are considered noise, i.e., the maximum ordnance detectable by the sensor and its accompanying false positive rate or background alarm rate.

e. Based on configuration of the ground truth at the standardized sites and the defined scoring methodology, there exists the possibility of having anomalies within overlapping halos and/or multiple anomalies within halos. In these cases, the following scoring logic is implemented:

(1) In situations where multiple anomalies exist within a single R_{halo}, the anomaly with the strongest response or highest ranking will be assigned to that particular ground truth item.

(2) For overlapping R_{halo} situations, ordnance has precedence over clutter. The anomaly with the strongest response or highest ranking that is closest to the center of a particular ground truth item gets assigned to that item. Remaining anomalies are retained until all matching is complete.

(3) Anomalies located within any R_{halo} that do not get associated with a particular ground truth item are thrown out and are not considered in the analysis.

f. All scoring factors are generated utilizing the Standardized UXO Probability and Plot Program, version 3.1.1.

1.2.2 Scoring Factors

Factors to be measured and evaluated as part of this demonstration include:

a. Response Stage ROC curves:

(1) Probability of Detection (P_d^{res}).

(2) Probability of False Positive (P_{fp}^{res}).

(3) Background Alarm Rate (BAR^{res}) or Probability of Background Alarm (P_{BA}^{res}).

b. Discrimination Stage ROC curves:

(1) Probability of Detection (P_d^{disc}).

(2) Probability of False Positive (P_{fp}^{disc}).

(3) Background Alarm Rate (BAR^{disc}) or Probability of Background Alarm (P_{BA}^{disc}).

c. Metrics:

(1) Efficiency (E).

(2) False Positive Rejection Rate (R_{fp}).

(3) Background Alarm Rejection Rate (R_{BA}).

d. Other:

(1) Probability of Detection by Size and Depth.

(2) Classification by type (i.e., 20-, 40-, 105-mm, etc.).

(3) Location accuracy.

(4) Equipment setup, calibration time and corresponding man-hour requirements.

(5) Survey time and corresponding man-hour requirements.

(6) Reacquisition/resurvey time and man-hour requirements (if any).

(7) Downtime due to system malfunctions and maintenance requirements.

1.3 STANDARD AND NONSTANDARD INERT ORDNANCE TARGETS

The standard and nonstandard ordnance items emplaced in the test areas are listed in Table 1. Standardized targets are members of a set of specific ordnance items that have identical properties to all other items in the set (caliber, configuration, size, weight, aspect ratio, material, filler, magnetic remanence, and nomenclature). Nonstandard targets are inert ordnance items having properties that differ from those in the set of standardized targets.

TABLE 1. INERT ORDNANCE TARGETS

Standard Type	Nonstandard (NS)
20-mm Projectile M55	20-mm Projectile M55
	20-mm Projectile M97
40-mm Grenades M385	40-mm Grenades M385
40-mm Projectile MKII Bodies	40-mm Projectile M813
BDU-28 Submunition	
BLU-26 Submunition	
M42 Submunition	
57-mm Projectile APC M86	
60-mm Mortar M49A3	60-mm Mortar (JPG)
	60-mm Mortar M49
2.75-inch Rocket M230	2.75-inch Rocket M230
	2.75-inch Rocket XM229
MK 118 ROCKEYE	
81-mm Mortar M374	81-mm Mortar (JPG)
	81-mm Mortar M374
105-mm Heat Rounds M456	
105-mm Projectile M60	105-mm Projectile M60
155-mm Projectile M483A1	155-mm Projectile M483A
	500-lb Bomb

JPG = Jefferson Proving Ground
HEAT = high-explosive, antitank

SECTION 2. DEMONSTRATION

2.1 DEMONSTRATOR INFORMATION

2.1.1 Demonstrator Point of Contact (POC) and Address

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2.1.2 System Description (provided by demonstrator)

The Simultaneous Multi-sensor Surface Towed Ordnance Location System (STOLS) is a Global Positioning System (GPS)-integrated vehicular towed array with the unique capability to simultaneously co-deploy total field magnetometers and electromagnetic (EM)61 sensors on a common platform. This approach combines the two sensors that have been demonstrated by multiple tests at JPG in the 1990s to be the most effective against UXO, and results in, effectively, two surveys for the price of one. This significantly improves site characterization and potential detection capability while reducing cost. The system was developed by GEO-CENTERS and Corps of Engineers-Huntsville Center (CEHNC) under Environmental Security Technology Certification Projects (ESTCP) project UX-0208, the goal of which was to integrate EM61s into GEO-CENTERS' existing STOLS towed magnetometer array. Normally, commercial off-the-shelf (COTS) EM61s and magnetometers cannot be co-deployed due to the noise engendered in the magnetometer data by the EM61's transmit pulses, but under the ESTCP-funded project, custom electronics were developed that interleave the two data streams, effectively sampling the magnetometers only during the period when the EM61s are quiet. Also funded was the development of a fiberglass proof-of-concept platform to host both the magnetometers in a very low-noise environment. Major portions of GEO-CENTERS original STOLS magnetometer-only towed array were utilized; the existing aluminum-framed low-magnetic self-signature tow vehicle, five cesium vapor total field magnetometers, three channels of EM61 MK1 (single time gate) electronics, three 1/2 by 1/2 meter coils, Trimble real time kinematic (RTK) equipped GPS capable of centimeter-level accuracy in real time, and data acquisition and data processing infrastructure were leveraged by the ESTCP-funded effort (fig. 1). The system also uses a stationary reference magnetometer to track the diurnal variations of the Earth's ambient magnetic field. These are later subtracted from the vehicle data during processing.

The ESTCP-funded system has been significantly improved through an ongoing Cooperative Research and Development Agreement (CRADA) between CEHNC and GEO-CENTERS. These improvements include updating the EM61 system to include five 1 by 1/2 meter coils (making the EM swath the same as the magnetometer swath width) driven by MKII multiple time gate electronics, the addition of a suspension to the original proof-of-concept

fiberglass towed platform, a ruggedized computer for data acquisition, and powering all EM61 electronics off a common isolated battery to eliminate drift and mitigate noise. The purchase of the new EM61 hardware was funded by ATC through the Army EQT program.

Figure 1. Demonstrator's system, STOLS/towed array.

Spacing and Sampling Rate: The magnetometers and EM61 coils are each at 1/2 meter spacing cross-track, with the five EM61 coils along the center line of the five magnetometers. The GPS antenna is directly over the center magnetometer. The down-track separation between the magnetometer array and the EM61 array is currently 8 feet, though this is an overly conservative artifact of the original ESTCP-funded design. Since the synchronized electronics sample the magnetometers during the period when the EM61 transmit pulse is quiet, the magnetometer sampling rate is the same as the EM61 transmit pulse rate - namely, 75 Hz. Like all COTS EM61s, the electronics average the data until they receive a signal from a tick wheel. An electrical circuit is used to divide the GPS 1 PPS into a 10 Hz tick signal and trigger the EM61 to output data. Thus, the EM61 data output rate is 10 Hz.

2.1.3 Data Processing Description (provided by demonstrator)

Multi-sensor vehicular survey data and the diurnal variation data. GPS data are read and converted into universal transverse mercator (UTM) coordinates to determine site physical extent. Sensor and position data are then processed and interpolated. The software then sets up a site (a grid in memory) which wholly contains the surveyed data. Then the position data are examined and corrected as needed. Automatic correction examines the position data for jumps greater than expected for typical survey speeds up to 12 miles per hour. The heading between

updates is determined and the position of the 75 Hz magnetometer and 10 Hz EM samples are calculated. If large jumps in the position data are encountered (e.g. jumps caused by short-term differential dropouts), the operator is asked to examine the data and manually correct a bad point by forcing it to align with the normal survey line. The corrected navigation data is then saved with the sensor data in a new file.

The magnetometer portion of the new navigation-corrected file is then processed with the temporally registered diurnal variation data. The diurnal data are subtracted from the survey magnetometer data to eliminate the effects of changes to the Earth's magnetic field during the course of the survey and to normalize the data around zero gamma. The diurnally corrected data are then interpolated into a 10 cm grid for image display. A linear interpolation is used, with an interpolation window of +/- 30 cm. This interpolation window functions in both directions - interpolation is performed cross-track (between the sensors spaced 1/2 meter apart) as well as along the direction of travel (between the 75 Hz magnetometer or 10 Hz EM updates). The final interpolated image is displayed and written as a separate file. Additional processing steps are sometimes used to create the best possible interpolated image. This sometimes involves removing small inter-magnetometer biases from the data to correct for minor sensor-to-sensor differences, removing small directional offsets from the data, and running a median filter on the time-series sensor updates to remove spurious data values. The interpolated images will be examined and a judgment will be made as to whether either of these or any other additional techniques are required. The EM portion of the data file will be processed in a similar fashion except that no diurnal variation data will be subtracted.

For this YPG exercise, processed data will be given to Dr. Steven Billings and Dr. Leonard Pasion, both of the University of British Columbia and Sky Research, Inc. Dr. Billings and Dr. Pasion will process both the magnetometer and EM61 data via inverse modeling techniques. Existing algorithms have been developed to use the degree of remnant magnetization as a discriminator of UXO from clutter, though the direct applicability of this technique to the APG site, where ordnance has been seeded and thus has not lost its moment due to shock demagnetization, is unknown. The beta technique, where the EM61 data is inverted and parameters related to object symmetry are used as UXO/clutter discriminators, will also be employed. In addition, Billings and Pasion will attempt to perform a cooperative inversion of both data sets. Plans are also to employ a statistical classifier for the discrimination.

2.1.4 Data Submission Format

Data were submitted for scoring in accordance with data submission protocols outlined in the Standardized UXO Technology Demonstration Site Handbook. These submitted data are not included in this report in order to protect ground truth information.

2.1.5 Demonstrator Quality Assurance (QA) and Quality Control (QC) (provided by demonstrator)

An automated data quality program examines the data and reports out-of-range magnetometer readings and bad (nondifferential) position readings. This gives a quick and convenient benchmark on out-of-range data that may be indicative of navigation or sensor errors. Typically this report is small enough to be entered manually into the site data processing and archive log.

Multi-sensor vehicular STOLS is a self-contained geophysical survey system that hosts up to five magnetometers and five 1 by 1/2 meter EM61 coils, a RTK differential GPS, an embedded computer/data logger, and operator input/output devices.

As deployed, STOLS performs continuous QCs with immediate operator feedback on system status. In addition to this self-monitoring feature, STOLS is set up with a comprehensive set of checklists for the Base Navigation Station, the Diurnal (magnetometer) Reference Station, the STOLS Field Technician, and Data Management. These checklists are filed daily and are available for review. Among the functionality that the checklists ensure are:

- Base GPS reference position and pseudo range correction values. If the reference position does not match the checklist, it is adjusted and verified. If the pseudo range correction values are excessive (any one correction value greater than 100 meters), the Base GPS reference position is checked again. This process insures that the Base GPS is performing within its performance envelope.

- Diurnal variation (reference magnetometer) station time synchronization with GPS time is verified, tuning value is checked, and initial battery and field strength values recorded.

- Multisensor STOLS is set up with a comprehensive field technician checklist. Data values are displayed on the screen during data acquisition.

- Because STOLS uses the GPS for position mapping sensor survey data, daily survey plans will be guided by the use of commercially available satellite planning software (Trimble's QuickPlan). This program allows the survey work to be scheduled during hours of peak GPS coverage, hence optimum positioning performance. Predicted positioning performance is determined by a GPS positioning accuracy parameter called Position Dilution of Precession (PDOP). PDOP values are predicted based on the general site location (WGS84 LAT/LON), time of day, number of available satellites in view, and satellite geometry.

- Seeded with the site location, a current GPS ephemeris file (current satellite constellation map available on-line or from the GPS receiver), minimum satellite elevation, and current date, QuickPlan displays the number of satellites in view and the corresponding PDOP for every moment of the day. PDOP values greater than 7.0 are used as an upper limit for acceptable positioning accuracy (lower PDOP values indicate higher positioning accuracy).

Note: The GPS rover receiver in the tow vehicle is programmed with a PDOP mask of 7.0. If this value is exceeded, the receiver fix quality drops to zero. This provides an automatic halt to data acquisition (after 15 seconds) and a warning alert message to the tow vehicle operator to wait for better positioning accuracy.

- An additional QuickPlan display shows satellite trajectories throughout the planned day to further assist in site investigation planning (e.g. if a high number of satellites lie to the west at low elevation during a certain part of the work day, they may be blocked by

the local buildings). All of this information is used to effectively plan the investigation workday. Workday times with unacceptable PDOP values are used for lunch breaks or other investigation tasks, including data transfer, processing, analysis, or logistics resupply.

A high degree of QC is attained through having trained personnel who know what acceptable and unacceptable data values operate the system. All values are displayed once per second for operator observation. Total field cesium vapor magnetometers are used for their high sensitivity (0.01 gammas) and high dynamic range (20,000 to 95,000 gamma). Magnetic field strengths outside this dynamic range result in a 0 output that is monitored by the data acquisition software. These sensors also have active and dead zones that interact with the local field direction. Both the sensor alignment/misalignment and sensor out of range are constantly monitored by the data acquisition software, and the operator is alerted to these error conditions. As delivered from the sensor manufacturer, these sensors either work or they don't work. Other than replacing failed sensors/cables, there are no operator calibration adjustments that can be made to the magnetometer array. There may be sensor-to-sensor offsets that are fixed or directionally sensitive which can be adjusted for at the data processing end, if required. The EM61 data for all lower and upper coils is displayed in real time. The operator may adjust the zero setting for each coil pair at the EM electronics or via a software background subtraction. The operator is trained to observe the EM output for baseline readings, acceptable noise levels, drift, and sensor failure. The rover differential GPS requires radio line of sight to the base navigation station and access to the local GPS satellite constellation. The data acquisition program monitors and assesses the navigation data quality for both of these conditions continuously and alerts the operator whenever there is a problem.

After a survey is complete and the data transferred, a separate program examines and reports on the navigation and sensor quality. The results of this report are typically entered manually onto the data processing and archiving log sheet.

The data processing end of STOLS is the largest measure of QC and assessment. At the workstation, raw data is archived, the navigation data is corrected for any jumps, and the 0.5 meter by 75 or 10 Hz sensor data is interpolated to a 10 cm grid for display. The visual quality of this image is the best indicator of system quality and can be scaled to optimally display individual magnetic or EM anomalies. Once this image is made, site-specific landmarks from each survey may be overlaid.

Target coordinates should overlay an anomaly in the image for visual correlation. This may also be done for the base navigation station location(s). Additionally, anomalies can be analyzed and their coordinates determined and compared with ground truth. Both techniques may be used.

Multi-sensor STOLS will be field-tested daily to ensure it is operating properly. If the standard response cannot be attained, the system will be repaired, or components replaced.

Failed or failing equipment will be replaced. Problems associated with low battery voltage (e.g. sensor drift) will require battery charging and possible resurveying.

QA procedures mandated by the Corps of Engineers will also be employed. These will include a daily static check and daily object spike test.

2.1.6 Additional Records

The following record(s) by this vendor can be accessed via the Internet as MicroSoft Word documents at www.uxotestsites.org.

2.2 YPG SITE INFORMATION

2.2.1 Location

YPG is located adjacent to the Colorado River in the Sonoran Desert. The UXO Standardized Test Site is located south of Pole Line Road and east of the Countermine Testing and Training Range. The Open Field range, Calibration Grid, Blind Grid, Mogul area, and Desert Extreme area comprise the 350 by 500-meter general test site area. The open field site is the largest of the test sites and measures approximately 200 by 350 meters. To the east of the open field range are the calibration and blind test grids that measure 30 by 40 meters and 40 by 40 meters, respectively. South of the Open Field is the 135- by 80-meter Mogul area consisting of a sequence of man-made depressions. The Desert Extreme area is located southeast of the open field site and has dimensions of 50 by 100 meters. The Desert Extreme area, covered with desert-type vegetation, is used to test the performance of different sensor platforms in a more severe desert conditions/environment.

2.2.2 Soil Type

Soil samples were collected at the YPG UXO Standardized Test Site by ERDC to characterize the shallow subsurface (< 3 m). Both surface grab samples and continuous soil borings were acquired. The soils were subjected to several laboratory analyses, including sieve/hydrometer, water content, magnetic susceptibility, dielectric permittivity, X-ray diffraction, and visual description.

There are two soil complexes present within the site, Riverbend-Carrizo and Cristobal-Gunsight. The Riverbend-Carrizo complex is comprised of mixed stream alluvium, whereas the Cristobal-Gunsight complex is derived from fan alluvium. The Cristobal-Gunsight complex covers the majority of the site. Most of the soil samples were classified as either a sandy loam or loamy sand, with most samples containing gravel-size particles. All samples had a measured water content less than 7 percent, except for two that contained 11-percent moisture. The majority of soil samples had water content between 1 to 2 percent. Samples containing more than 3 percent were generally deeper than 1 meter.

An X-ray diffraction analysis on four soil samples indicated a basic mineralogy of quartz, calcite, mica, feldspar, magnetite, and some clay. The presence of magnetite imparted a moderate magnetic susceptibility, with volume susceptibilities generally greater than 100 by 10-5 SI.

For more details concerning the soil properties at the YPG test site, go to www.uxotestsites.org on the web to view the entire soils description report.

2.2.3 Test Areas

A description of the test site areas at YPG is included in Table 2.

TABLE 2. TEST SITE AREAS

Area	Description
Calibration Grid	Contains the 15 standard ordnance items buried in six positions at various angles and depths to allow demonstrator equipment calibration.
Blind Grid	Contains 400 grid cells in a 0.16-hectare (0.39-acre) site. The center of each grid cell contains ordnance, clutter, or nothing.

SECTION 3. FIELD DATA

3.1 DATE OF FIELD ACTIVITIES (18 through 20 October 2004)

3.2 AREAS TESTED/NUMBER OF HOURS

Areas tested and total number of hours operated at each site are summarized in Table 3.

TABLE 3. AREAS TESTED AND NUMBER OF HOURS

Area	Number of Hours
Calibration Lanes	0.43
Blind Grid	2.57

3.3 TEST CONDITIONS

3.3.1 Weather Conditions

A YPG weather station located approximately one mile west of the test site was used to record average temperature and precipitation on a half hour basis for each day of operation. The temperatures listed in Table 4 represent the average temperature during field operations from 0700 to 1700 hours while precipitation data represents a daily total amount of rainfall. Hourly weather logs used to generate this summary are provided in Appendix B.

TABLE 4. TEMPERATURE/PRECIPITATION DATA SUMMARY

Date, 2004	Average Temperature, ^{o}F	Total Daily Precipitation, in.
18 October	75.90	0.00
19 October	74.93	0.00
20 October	76.50	0.00

3.3.2 Field Conditions

GEO-CENTERS surveyed the Blind Grid from 18 through 20 October 2004. The Calibration Lanes and Blind Grid were dry and the weather was warm.

3.3.3 Soil Moisture

Three soil probes were placed at various locations within the site to capture soil moisture data: Calibration, Mogul, Open Field, and Wooded areas. Measurements were collected in percent moisture and were taken twice daily (morning and afternoon) from five different soil depths (1 to 6 in., 6 to 12 in., 12 to 24 in., 24 to 36 in., and 36 to 48 in.) from each probe. Soil moisture logs are included in Appendix C.

3.4 FIELD ACTIVITIES

3.4.1 Setup/Mobilization

These activities included initial mobilization and daily equipment preparation and break down. A crew of 2 people took 2 hours and 54 minutes to perform the initial setup and mobilization. Daily equipment preparation took no time in the Blind Grid. Equipment breakdown took 21 minutes in the Blind Test Grid.

3.4.2 Calibration

GEO-CENTERS worked in the Calibration Lanes on the 18 of October for 26 minutes, all of which was spent collecting data. No other calibration activities occurred while surveying the Blind Grid.

3.4.3 Downtime Occasions

Occasions of downtime are grouped into five categories: equipment/data checks or equipment maintenance, equipment failure and repair, weather, Demonstration Site issues, or breaks/lunch. All downtime is included for the purposes of calculating labor costs (section 5) except for downtime due to Demonstration Site issues. Demonstration Site issues, while noted in the Daily Log, are considered nonchargeable downtime for the purposes of calculating labor costs and are not discussed. Breaks and lunches are discussed in this section and billed to the total Site Survey area.

3.4.3.1 Equipment/data checks, maintenance. Equipment/data checks and maintenance activities accounted for 26 minutes of site usage time while surveying in the Blind Grid. An additional 40 minutes were spent on breaks and lunches.

3.4.3.2 Equipment failure or repair. No time was needed to resolve equipment failures that occurred while surveying the Blind Grid.

3.4.3.3 Weather. No weather delays occurred during the survey.

3.4.4 Data Collection

GEO-CENTERS spent a total of 2 hours and 34 minutes in the Blind Grid, of which 1 hour and 7 minutes was spent collecting data.

3.4.5 Demobilization

The GEO-CENTERS survey crew went on to conduct a full demonstration of the site. Therefore, demobilization did not occur until 20 October 2004. On that day, it took the crew 1 hour and 53 minutes to break down and pack up their equipment.

3.5 PROCESSING TIME

GEO-CENTERS submitted the raw data from the demonstration activities on the last day of the demonstration, as required. The scoring submittal data was also provided within the required 30-day timeframe.

3.6 DEMONSTRATOR'S FIELD PERSONNEL

Robert Siegel, GEO-CENTERS, Project Manager and Data Analyst
David Fanning, under contract to GEO-CENTERS, truck driver
Alan Crandall, under contract to GEO-CENTERS, U.S. Environmental, Field Supervisor

3.7 DEMONSTRATOR'S FIELD SURVEYING METHOD

GEO-CENTERS began surveyed the Blind Grid in two directions, south to north and east to west.

3.8 SUMMARY OF DAILY LOGS

Daily logs capture all field activities during this demonstration and are located in Appendix D. Activities pertinent to this specific demonstration are indicated in highlighted text.

SECTION 4. TECHNICAL PERFORMANCE RESULTS

4.1 ROC CURVES USING ALL ORDNANCE CATEGORIES

Figure 2, 4, and 6 shows the probability of detection for the response stage (P_d^{res}) and the discrimination stage (P_d^{disc}) versus their respective probability of false positive for the EM sensor(s), MAG sensor(s) and combined EM/MAG picks respectively. Figure 3, 5, and 7 shows both probabilities plotted against their respective probability of background alarm. Both figures use horizontal lines to illustrate the performance of the demonstrator at two demonstrator-specified points: at the system noise level for the response stage, representing the point below which targets are not considered detectable, and at the demonstrator's recommended threshold level for the discrimination stage, defining the subset of targets the demonstrator would recommend digging based on discrimination. Note that all points have been rounded to protect the ground truth.

The overall ground truth is composed of ferrous and non-ferrous anomalies. Due to limitations of the magnetometer, the non-ferrous items cannot be detected. Therefore, the ROC curves presented in figures 4 and 5 of this section are based on the subset of the ground truth that is solely made up of ferrous anomalies.

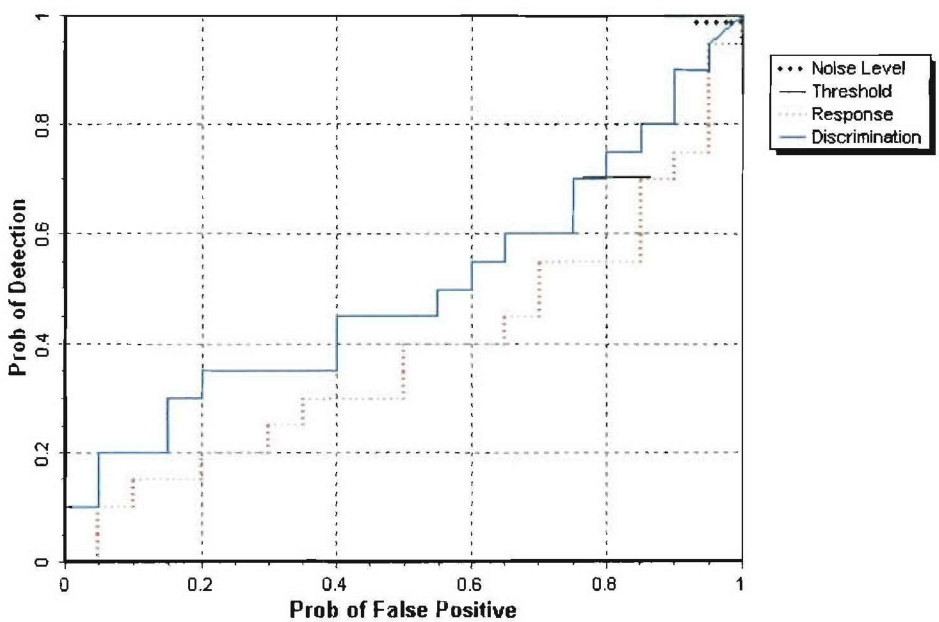

Figure 2. EM Sensor blind grid probability of detection for response and discrimination stages versus their respective probability of false positive over all ordnance categories combined.

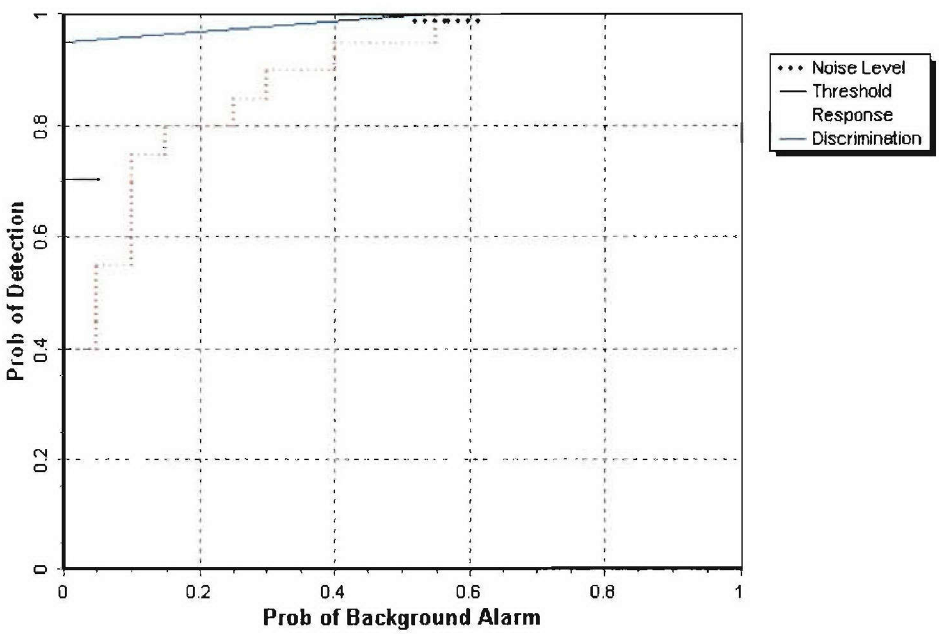

Figure 3. EM Sensor blind grid probability of detection for response and discrimination stages versus their respective probability of background alarm over all ordnance categories combined.

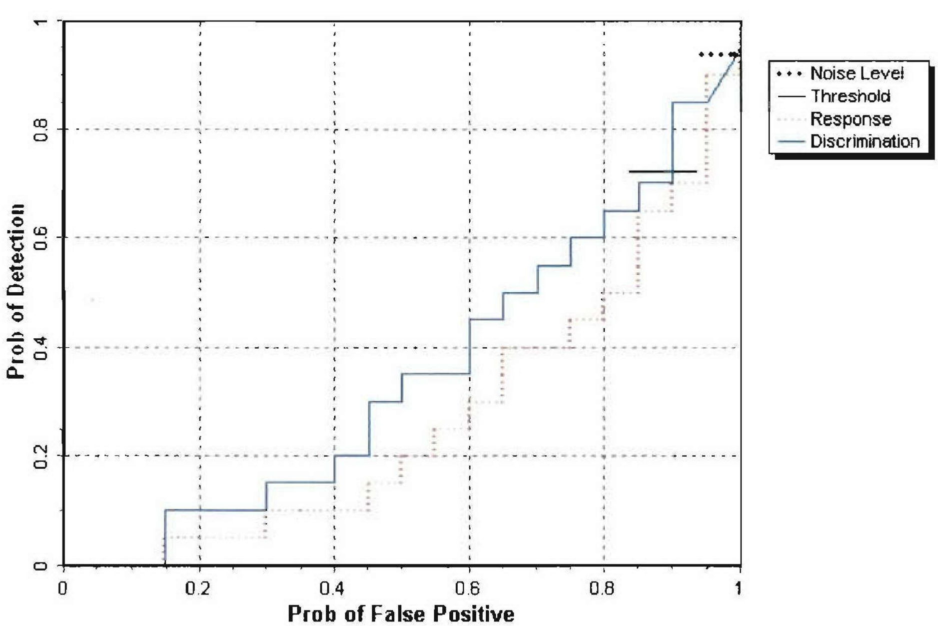

Figure 4. MAG Sensor blind grid probability of detection for response and discrimination stages versus their respective probability of false positive over all ordnance categories combined.

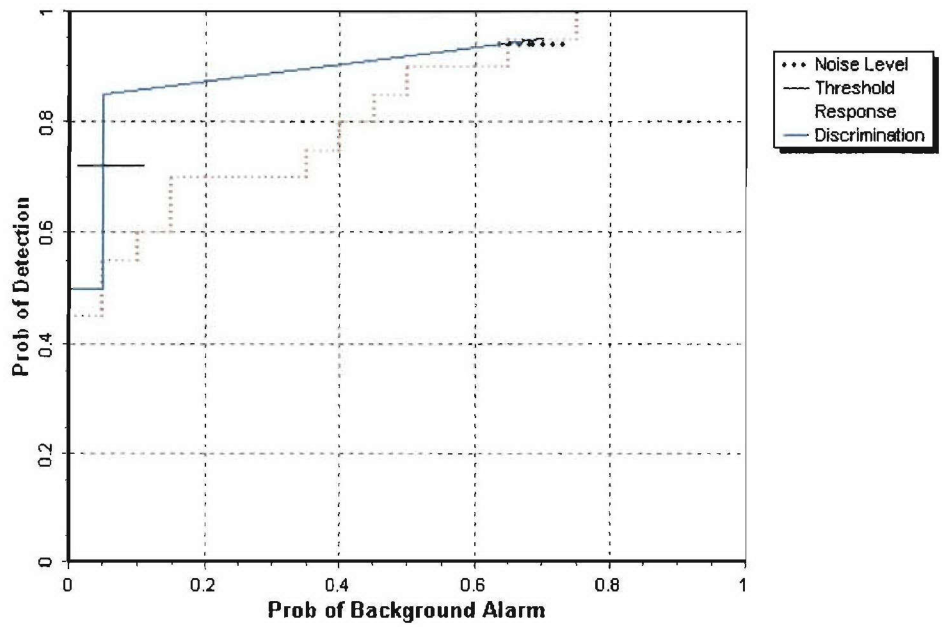

Figure 5. MAG Sensor blind grid probability of detection for response and discrimination stages versus their respective probability of background alarm over all ordnance categories combined.

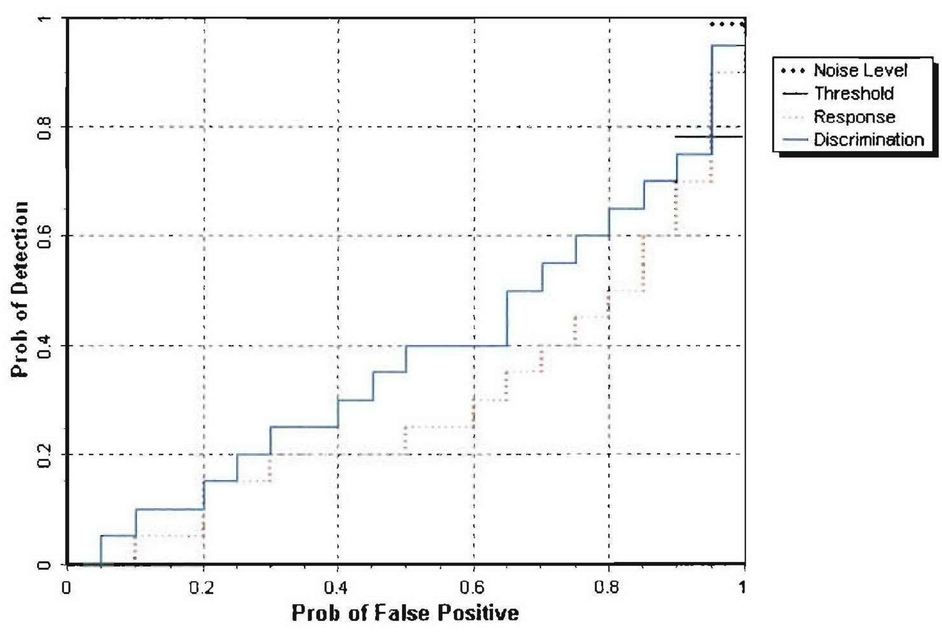

Figure 6. Combined Sensor blind grid probability of detection for response and discrimination stages versus their respective probability of false positive over all ordnance categories combined.

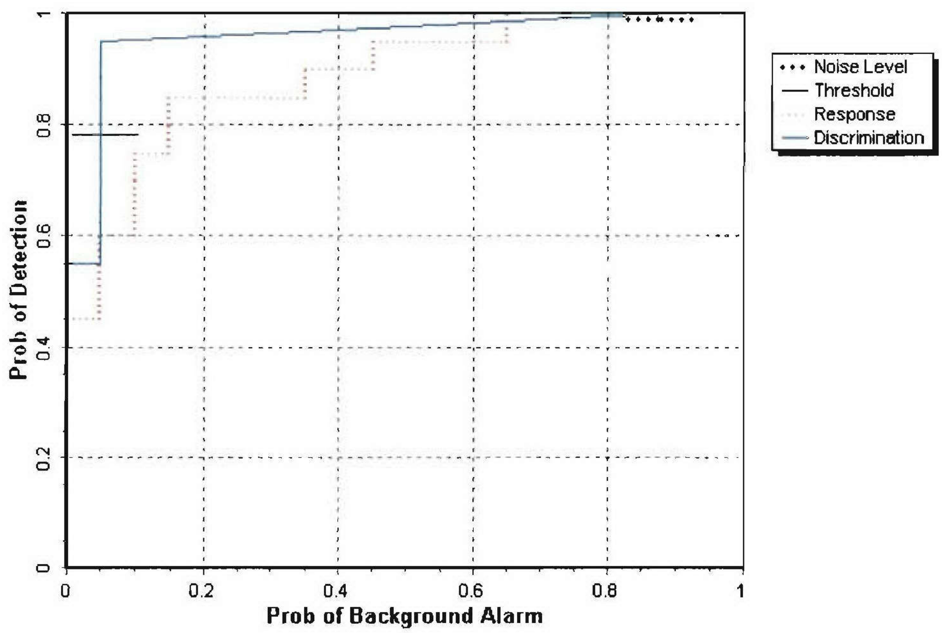

Figure 7. Combined Sensor blind grid probability of detection for response and discrimination stages versus their respective probability of background alarm over all ordnance categories combined.

4.2 ROC CURVES USING ORDNANCE LARGER THAN 20 MM

Figure 8, 10, and 12 shows the probability of detection for the response stage (P_d^{res}) and the discrimination stage (P_d^{disc}) versus their respective probability of false positive when only targets larger than 20 mm are scored for the EM sensor(s), MAG sensor(s) and Combined EM/MAG picks respectively. Figure 9, 11, and 13 shows both probabilities plotted against their respective probability of background alarm. Both figures use horizontal lines to illustrate the performance of the demonstrator at two demonstrator-specified points: at the system noise level for the response stage, representing the point below which targets are not considered detectable, and at the demonstrator's recommended threshold level for the discrimination stage, defining the subset of targets the demonstrator would recommend digging based on discrimination. Note that all points have been rounded to protect the ground truth.

The overall ground truth is composed of ferrous and non-ferrous anomalies. Due to limitations of the magnetometer, the non-ferrous items cannot be detected. Therefore, the ROC curves presented in figures 10 and 11 of this section are based on the subset of the ground truth that is solely made up of ferrous anomalies.

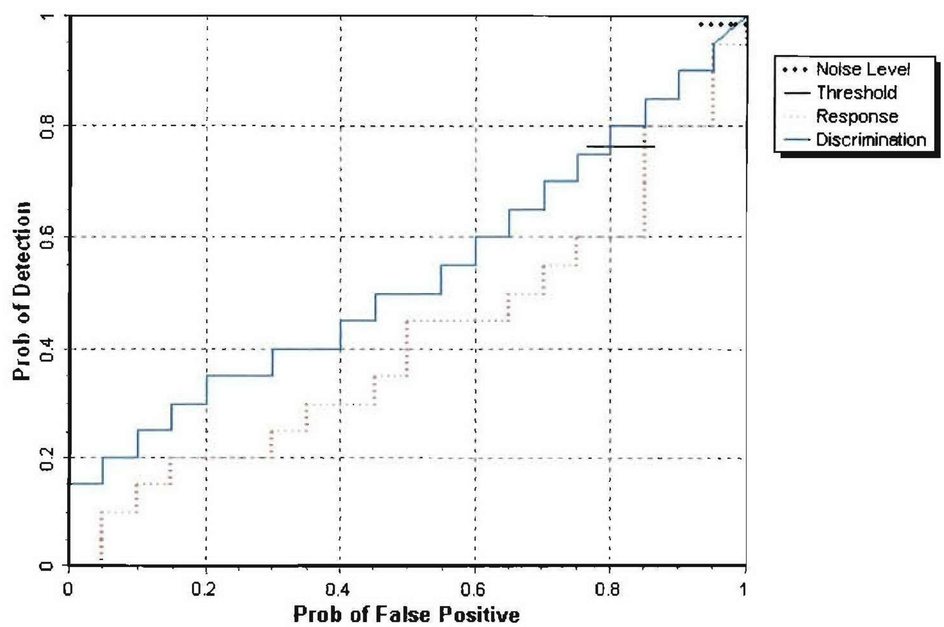

Figure 8. EM Sensor blind grid probability of detection for response and discrimination stages versus their respective probability of false positive for all ordnance larger than 20 mm.

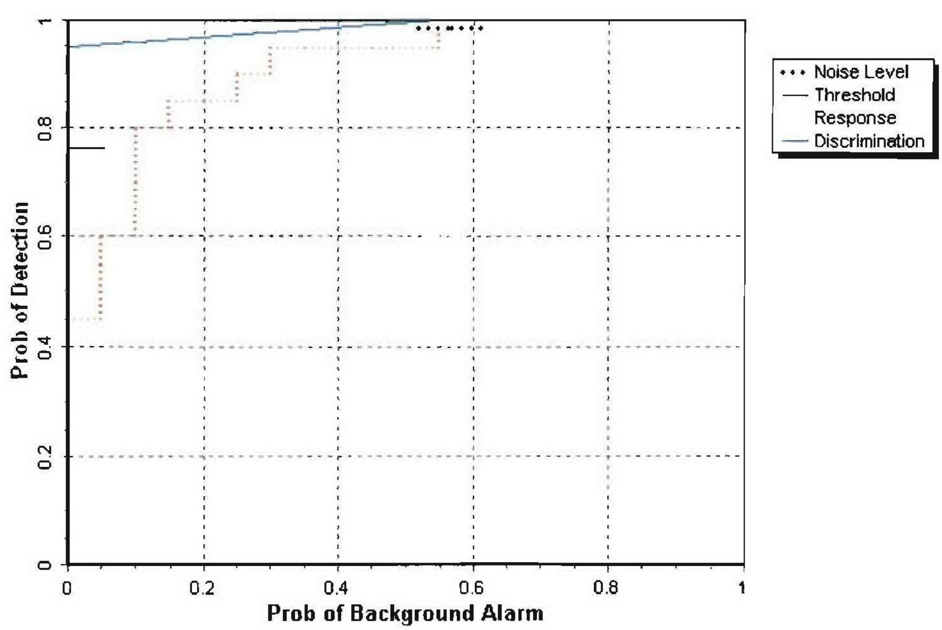

Figure 9. EM Sensor blind grid probability of detection for response and discrimination stages versus their respective probabilities of background alarm for all ordnance larger than 20 mm.

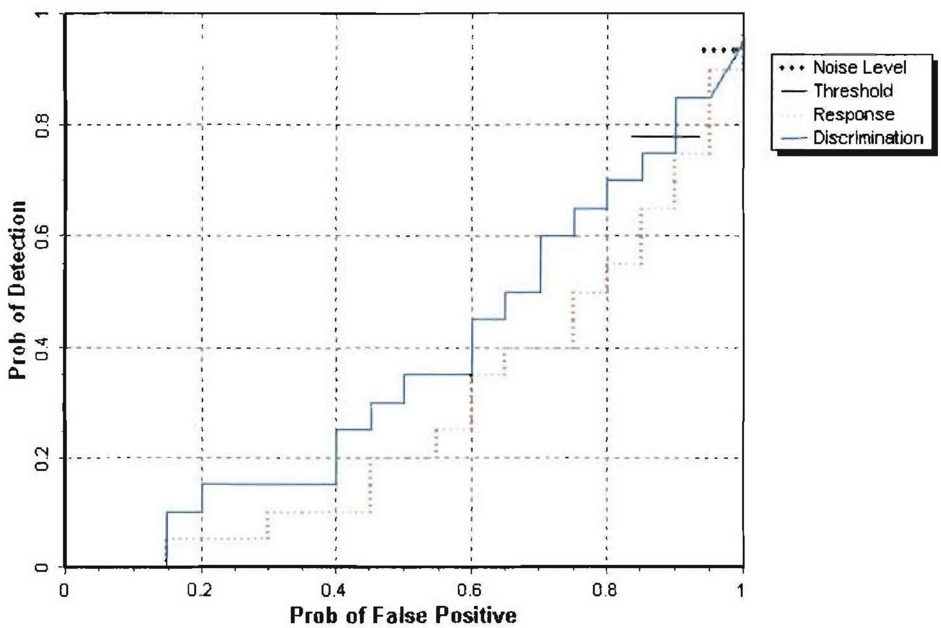

Figure 10. MAG Sensor blind grid probability of detection for response and discrimination stages versus their respective probability of false positive for all ordnance larger than 20 mm.

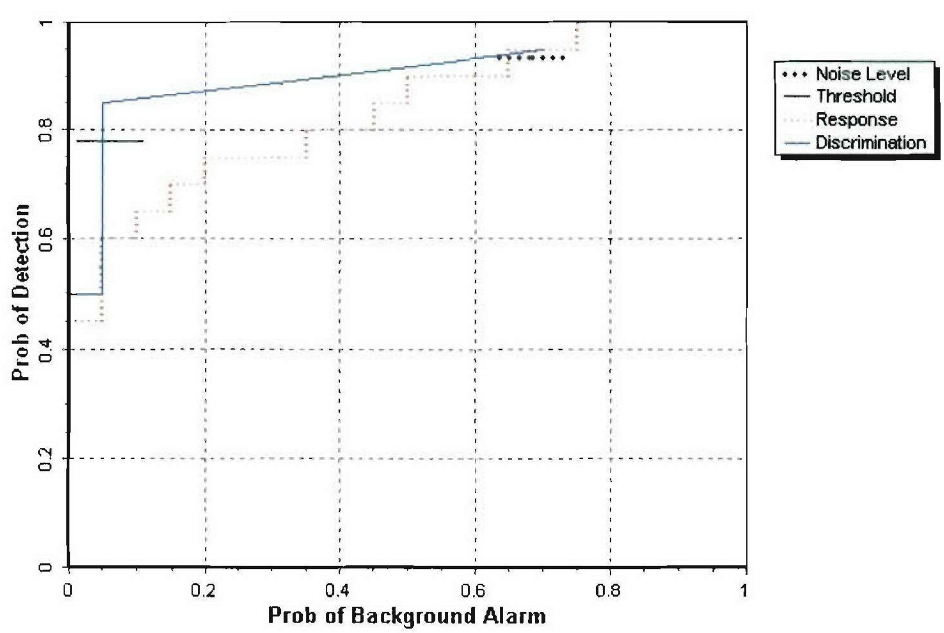

Figure 11. MAG Sensor blind grid probability of detection for response and discrimination stages versus their respective probabilities of background alarm for all ordnance larger than 20 mm.

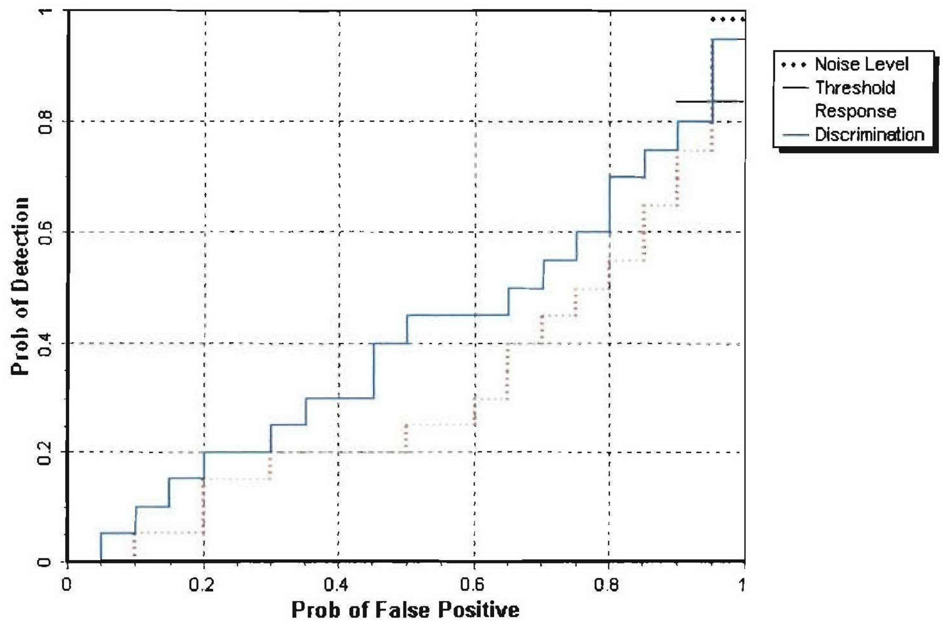

Figure 12. Combined Sensor blind grid probability of detection for response and discrimination stages versus their respective probability of false positive for all ordnance larger than 20 mm.

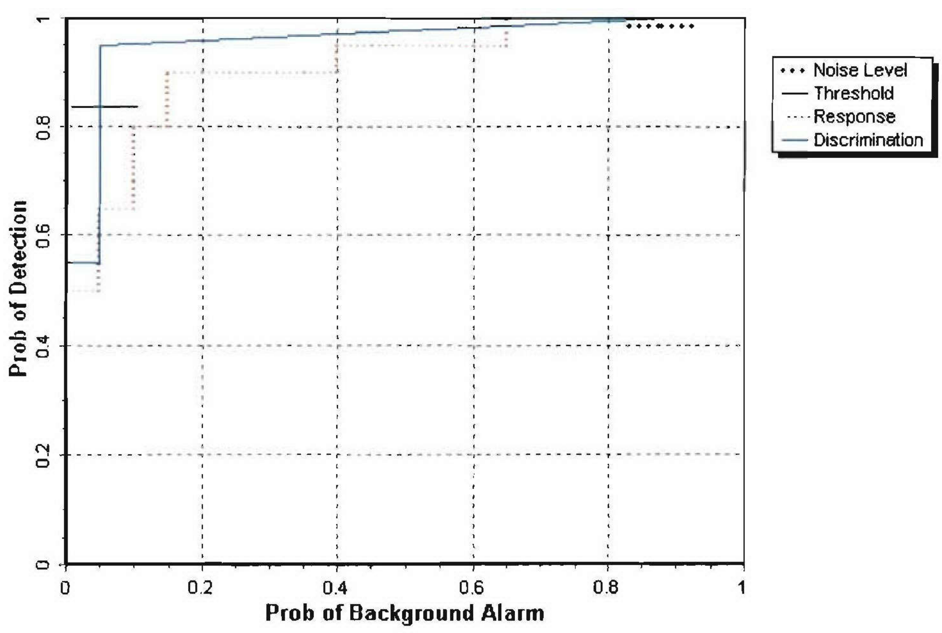

Figure 13. Combined Sensor blind grid probability of detection for response and discrimination stages versus their respective probabilities of background alarm for all ordnance larger than 20 mm.

4.3 PERFORMANCE SUMMARIES

Results for the Blind Grid test broken out by sensor type, size, depth and nonstandard ordnance are presented in Tables 5a, b, and c (for cost results, see section 5). Results by size and depth include both standard and nonstandard ordnance. The results by size show how well the demonstrator did at detecting/discriminating ordnance of a certain caliber range (see app A for size definitions). The results are relative to the number of ordnance items emplaced. Depth is measured from the geometric center of anomalies.

The RESPONSE STAGE results are derived from the list of anomalies above the demonstrator-provided noise level. The results for the DISCRIMINATION STAGE are derived from the demonstrator's recommended threshold for optimizing UXO field cleanup by minimizing false digs and maximizing ordnance recovery. The lower 90 percent confidence limit on probability of detection and P_{fp} was calculated assuming that the number of detections and false positives are binomially distributed random variables. All results in Table 5 have been rounded to protect the ground truth. However, lower confidence limits were calculated using actual results.

The overall ground truth is composed of ferrous and non-ferrous anomalies. Due to limitations of the magnetometer, the non-ferrous items cannot be detected. Therefore, the summary presented in Table 5b is split exhibiting results based on the subset of the ground truth that is solely the ferrous anomalies and the full ground truth for comparison purposes.

All other tables presented in this section are based on scoring against the ferrous only ground truth. The response stage noise level and recommended discrimination stage threshold values are provided by the demonstrator.

TABLE 5a. SUMMARY OF BLIND GRID RESULTS FOR THE STOLS/TOWED ARRAY (EM SENSOR)

Metric	Overall	Standard	Nonstandard	By Size			By Depth, m		
				Small	Medium	Large	< 0.3	0.3 to <1	>= 1
RESPONSE STAGE									
P_d	1.00	1.00	1.00	0.95	1.00	1.00	1.00	0.95	1.00
P_d Low 90% Conf	0.95	0.92	0.92	0.90	0.90	0.85	0.95	0.85	0.72
P_d Upper 90% Conf	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
P_{fp}	1.00	-	-	-	-	-	1.00	1.00	0.00
P_{fp} Low 90% Conf	0.95	-	-	-	-	-	0.94	0.92	-
P_{fp} Upper 90% Conf	1.00	-	-	-	-	-	0.99	1.00	-
P_{ba}	0.55	-	-	-	-	-	-	-	-
DISCRIMINATION STAGE									
P_d	0.70	0.75	0.60	0.45	0.90	1.00	0.60	0.90	0.70
P_d Low 90% Conf	0.62	0.65	0.48	0.35	0.78	0.85	0.47	0.79	0.40
P_d Upper 90% Conf	0.77	0.84	0.74	0.58	0.98	1.00	0.68	0.98	0.92
P_{fp}	0.80	-	-	-	-	-	0.75	0.95	0.00
P_{fp} Low 90% Conf	0.76	-	-	-	-	-	0.70	0.87	-
P_{fp} Upper 90% Conf	0.86	-	-	-	-	-	0.83	1.00	-
P_{ba}	0.00	-	-	-	-	-	-	-	-

Response Stage Noise Level: 5.20
Recommended Discrimination Stage Threshold: 4.00

TABLE 5b. SUMMARY OF BLIND GRID RESULTS FOR THE STOLS/TOWED ARRAY (MAG SENSOR)

Ferrous Only Ground Truth									
				By Size			By Depth, m		
Metric	Overall	Standard	Nonstandard	Small	Medium	Large	< 0.3	0.3 to <1	>= 1
RESPONSE STAGE									
P_d	0.95	0.90	1.00	0.90	1.00	1.00	0.90	1.00	1.00
P_d Low 90% Conf	0.90	0.83	0.92	0.78	0.90	0.85	0.82	0.90	0.72
P_d Upper 90% Conf	0.98	0.97	1.00	0.96	1.00	1.00	0.97	1.00	1.00
P_{fp}	1.00	-	-	-	-	-	1.00	1.00	0.00
P_{fp} Low 90% Conf	0.97	-	-	-	-	-	0.96	0.92	-
P_{fp} Upper 90% Conf	1.00	-	-	-	-	-	1.00	1.00	-
P_{ba}	0.70	-	-	-	-	-	-	-	-
DISCRIMINATION STAGE									
P_d	0.70	0.65	0.80	0.50	0.85	1.00	0.60	0.95	0.55
P_d Low 90% Conf	0.64	0.54	0.68	0.36	0.68	0.85	0.49	0.83	0.28
P_d Upper 90% Conf	0.80	0.76	0.91	0.64	0.92	1.00	0.72	1.00	0.83
P_{fp}	0.90	-	-	-	-	-	0.85	0.95	0.00
P_{fp} Low 90% Conf	0.84	-	-	-	-	-	0.81	0.82	-
P_{fp} Upper 90% Conf	0.92	-	-	-	-	-	0.92	0.98	-
P_{ba}	0.05	-	-	-	-	-	-	-	-

Full Ground Truth									
				By Size			By Depth, m		
Metric	Overall	Standard	Nonstandard	Small	Medium	Large	< 0.3	0.3 to <1	>= 1
RESPONSE STAGE									
P_d	0.95	0.90	0.95	0.85	1.00	1.00	0.90	0.95	1.00
P_d Low 90% Conf	0.88	0.83	0.87	0.76	0.90	0.85	0.82	0.85	0.72
P_d Upper 90% Conf	0.97	0.96	1.00	0.93	1.00	1.00	0.96	1.00	1.00
P_{fp}	1.00	-	-	-	-	-	1.00	1.00	0.00
P_{fp} Low 90% Conf	0.97	-	-	-	-	-	0.96	0.92	
P_{fp} Upper 90% Conf	1.00	-	-	-	-	-	1.00	1.00	
P_{ba}	0.70	-	-	-	-	-	-	-	-
DISCRIMINATION STAGE									
P_d	0.65	0.60	0.80	0.45	0.85	1.00	0.55	0.90	0.55
P_d Low 90% Conf	0.58	0.47	0.67	0.32	0.68	0.85	0.45	0.74	0.28
P_d Upper 90% Conf	0.74	0.68	0.89	0.55	0.92	1.00	0.66	0.95	0.83
P_{fp}	0.90	-	-	-	-	-	0.85	0.95	0.00
P_{fp} Low 90% Conf	0.84	-	-	-	-	-	0.81	0.82	-
P_{fp} Upper 90% Conf	0.92	-	-	-	-	-	0.92	0.98	-
P_{ba}	0.05	-	-	-	-	-	-	-	-

Response Stage Noise Level: 2.40
Recommended Discrimination Stage Threshold: 0.04

TABLE 5c. SUMMARY OF BLIND GRID RESULTS FOR THE STOLS/TOWED ARRAY (COMBINED RESULTS)

Metric	Overall	Standard	Nonstandard	By Size			By Depth, m		
				Small	Medium	Large	< 0.3	0.3 to <1	>= 1
RESPONSE STAGE									
P_d	1.00	1.00	1.00	0.95	1.00	1.00	1.00	0.95	1.00
P_d Low 90% Conf	0.95	0.92	0.92	0.90	0.90	0.85	0.95	0.85	0.72
P_d Upper 90% Conf	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
P_{fp}	1.00	-	-	-	-	-	1.00	1.00	0.00
P_{fp} Low 90% Conf	0.98	-	-	-	-	-	0.97	0.92	-
P_{fp} Upper 90% Conf	1.00	-	-	-	-	-	1.00	1.00	-
P_{ba}	0.90	-	-	-	-	-	-	-	-
DISCRIMINATION STAGE									
P_d	0.80	0.75	0.85	0.60	0.90	1.00	0.70	0.90	0.70
P_d Low 90% Conf	0.71	0.63	0.74	0.50	0.78	0.85	0.61	0.79	0.40
P_d Upper 90% Conf	0.85	0.82	0.94	0.73	0.98	1.00	0.81	0.98	0.92
P_{fp}	0.95	-	-	-	-	-	0.95	0.95	0.00
P_{fp} Low 90% Conf	0.91	-	-	-	-	-	0.89	0.87	-
P_{fp} Upper 90% Conf	0.97	-	-	-	-	-	0.97	1.00	-
P_{ba}	0.05	-	-	-	-	-	-	-	-

Response Stage Noise Level: 4.80
Recommended Discrimination Stage Threshold: 0.60

Note: The recommended discrimination stage threshold values are provided by the demonstrator.

4.4 EFFICIENCY, REJECTION RATES, AND TYPE CLASSIFICATION (All results based on Combined EM/MAG data set)

Efficiency and rejection rates are calculated to quantify the discrimination ability at specific points of interest on the ROC curve: (1) at the point where no decrease in P_d is suffered (i.e., the efficiency is by definition equal to one) and (2) at the operator selected threshold. These values are reported in Table 6.

TABLE 6. EFFICIENCY AND REJECTION RATES

	Efficiency (E)	False Positive Rejection Rate	Background Alarm Rejection Rate
At Operating Point	0.79	0.05	0.94
With No Loss of P_d	1.00	0.00	0.00

At the demonstrator's recommended setting, the ordnance items that were detected and correctly discriminated were further scored on whether their correct type could be identified (table 7). Correct type examples include "20-mm projectile, 105-mm HEAT Projectile, and 2.75-inch Rocket". A list of the standard type declaration required for each ordnance item was provided to demonstrators prior to testing. For example, the standard type for the three example items are 20mmP, 105H, and 2.75in, respectively.

TABLE 7. CORRECT TYPE CLASSIFICATION OF TARGETS CORRECTLY DISCRIMINATED AS UXO

Size	Percentage Correct
Small	NA
Medium	NA
Large	NA
Overall	NA

4.5 LOCATION ACCURACY

The mean location error and standard deviations appear in Table 8. These calculations are based on average missed depth for ordnance correctly identified in the discrimination stage. Depths are measured from the closest point of the ordnance to the surface. For the Blind Grid, only depth errors are calculated, since (X, Y) positions are known to be the centers of each grid square.

TABLE 8. MEAN LOCATION ERROR AND STANDARD DEVIATION (M)

	Mean	Standard Deviation
Depth	0.22	0.20

SECTION 5. ON-SITE LABOR COSTS

A standardized estimate for labor costs associated with this effort was calculated as follows: the first person at the test site was designated "supervisor", the second person was designated "data analyst", and the third and following personnel were considered "field support". Standardized hourly labor rates were charged by title: supervisor at $95.00/hour, data analyst at $57.00/hour, and field support at $28.50/hour.

Government representatives monitored on-site activity. All on-site activities were grouped into one of ten categories: initial setup/mobilization, daily setup/stop, calibration, collecting data, downtime due to break/lunch, downtime due to equipment failure, downtime due to equipment/data checks or maintenance, downtime due to weather, downtime due to demonstration site issue, or demobilization. See Appendix D for the daily activity log. See section 3.4 for a summary of field activities.

The standardized cost estimate associated with the labor needed to perform the field activities is presented in Table 9. Note that calibration time includes time spent in the Calibration Lanes as well as field calibrations. "Site survey time" includes daily setup/stop time, collecting data, breaks/lunch, downtime due to equipment/data checks or maintenance, downtime due to failure, and downtime due to weather.

TABLE 9. ON-SITE LABOR COSTS

	No. People	Hourly Wage	Hours	Cost
		INITIAL SETUP		
Supervisor	1	$95.00	2.90	$275.50
Data Analyst	1	57.00	2.90	165.30
Field Support	0	28.50	2.90	0.00
Subtotal				**$440.80**
		CALIBRATION		
Supervisor	1	$95.00	0.43	$40.85
Data Analyst	1	57.00	0.43	24.51
Field Support	0	28.50	0.43	0.00
Subtotal				**$65.36**
		SITE SURVEY		
Supervisor	1	$95.00	2.57	$44.15
Data Analyst	1	57.00	2.57	146.49
Field Support	0	28.50	2.57	0.00
Subtotal				**$390.64**

See notes at end of table.

TABLE 9 (CONT'D)

	No. People	Hourly Wage	Hours	Cost
DEMOBILIZATION				
Supervisor	1	$95.00	1.88	$178.60
Data Analyst	1	57.00	1.88	107.16
Field Support	0	28.50	1.88	0.00
Subtotal				**$285.76**
Total				**$1,182.56**

Notes: Calibration time includes time spent in the Calibration Lanes as well as calibration before each data run.

Site Survey time includes daily setup/stop time, collecting data, breaks/lunch, downtime due to system maintenance, failure, and weather.

SECTION 6. COMPARISON OF RESULTS TO DATE

No comparisons to date.

SECTION 7. APPENDIXES

APPENDIX A. TERMS AND DEFINITIONS

GENERAL DEFINITIONS

Anomaly: Location of a system response deemed to warrant further investigation by the demonstrator for consideration as an emplaced ordnance item.

Detection: An anomaly location that is within R_{halo} of an emplaced ordnance item.

Emplaced Ordnance: An ordnance item buried by the government at a specified location in the test site.

Emplaced Clutter: A clutter item (i.e., non-ordnance item) buried by the government at a specified location in the test site.

R_{halo}: A pre-determined radius about the periphery of an emplaced item (clutter or ordnance) within which a location identified by the demonstrator as being of interest is considered to be a response from that item. If multiple declarations lie within R_{halo} of any item (clutter or ordnance), the declaration with the highest signal output within the R_{halo} will be utilized. For the purpose of this program, a circular halo 0.5 meters in radius will be placed around the center of the object for all clutter and ordnance items less than 0.6 meters in length. When ordnance items are longer than 0.6 meters, the halo becomes an ellipse where the minor axis remains 1 meter and the major axis is equal to the length of the ordnance plus 1 meter.

Small Ordnance: Caliber of ordnance less than or equal to 40 mm (includes 20-mm projectile, 40-mm projectile, submunitions BLU-26, BLU-63, and M42).

Medium Ordnance: Caliber of ordnance greater than 40 mm and less than or equal to 81 mm (includes 57-mm projectile, 60-mm mortar, 2.75 in. Rocket, MK118 Rockeye, 81-mm mortar).

Large Ordnance: Caliber of ordnance greater than 81 mm (includes 105-mm HEAT, 105-mm projectile, 155-mm projectile, 500-pound bomb).

Shallow: Items buried less than 0.3 meter below ground surface.

Medium: Items buried greater than or equal to 0.3 meter and less than 1 meter below ground surface.

Deep: Items buried greater than or equal to 1 meter below ground surface.

Response Stage Noise Level: The level that represents the point below which anomalies are not considered detectable. Demonstrators are required to provide the recommended noise level for the Blind Grid test area.

Discrimination Stage Threshold: The demonstrator selected threshold level that they believe provides optimum performance of the system by retaining all detectable ordnance and rejecting the maximum amount of clutter. This level defines the subset of anomalies the demonstrator would recommend digging based on discrimination.

Binomially Distributed Random Variable: A random variable of the type which has only two possible outcomes, say success and failure, is repeated for n independent trials with the probability p of success and the probability 1-p of failure being the same for each trial. The number of successes x observed in the n trials is an estimate of p and is considered to be a binomially distributed random variable.

RESPONSE AND DISCRIMINATION STAGE DATA

The scoring of the demonstrator's performance is conducted in two stages. These two stages are termed the RESPONSE STAGE and DISCRIMINATION STAGE. For both stages, the probability of detection (P_d) and the false alarms are reported as receiver operating characteristic (ROC) curves. False alarms are divided into those anomalies that correspond to emplaced clutter items, measuring the probability of false positive (P_{fp}) and those that do not correspond to any known item, termed background alarms.

The RESPONSE STAGE scoring evaluates the ability of the system to detect emplaced targets without regard to ability to discriminate ordnance from other anomalies. For the RESPONSE STAGE, the demonstrator provides the scoring committee with the location and signal strength of all anomalies that the demonstrator has deemed sufficient to warrant further investigation and/or processing as potential emplaced ordnance items. This list is generated with minimal processing (e.g., this list will include all signals above the system noise threshold). As such, it represents the most inclusive list of anomalies.

The DISCRIMINATION STAGE evaluates the demonstrator's ability to correctly identify ordnance as such, and to reject clutter. For the same locations as in the RESPONSE STAGE anomaly list, the DISCRIMINATION STAGE list contains the output of the algorithms applied in the discrimination-stage processing. This list is prioritized based on the demonstrator's determination that an anomaly location is likely to contain ordnance. Thus, higher output values are indicative of higher confidence that an ordnance item is present at the specified location. For electronic signal processing, priority ranking is based on algorithm output. For other systems, priority ranking is based on human judgment. The demonstrator also selects the threshold that the demonstrator believes will provide "optimum" system performance, (i.e., that retains all the detected ordnance and rejects the maximum amount of clutter).

Note: The two lists provided by the demonstrator contain identical numbers of potential target locations. They differ only in the priority ranking of the declarations.

RESPONSE STAGE DEFINITIONS

Response Stage Probability of Detection (P_d^{res}): P_d^{res} = (No. of response-stage detections)/(No. of emplaced ordnance in the test site).

Response Stage False Positive (fp^{res}): An anomaly location that is within R_{halo} of an emplaced clutter item.

Response Stage Probability of False Positive (P_{fp}^{res}): P_{fp}^{res} = (No. of response-stage false positives)/(No. of emplaced clutter items).

Response Stage Background Alarm (ba^{res}): An anomaly in a blind grid cell that contains neither emplaced ordnance nor an emplaced clutter item. An anomaly location in the open field or scenarios that is outside R_{halo} of any emplaced ordnance or emplaced clutter item.

Response Stage Probability of Background Alarm (P_{ba}^{res}): Blind Grid only: P_{ba}^{res} = (No. of response-stage background alarms)/(No. of empty grid locations).

Response Stage Background Alarm Rate (BAR^{res}): Open Field only: BAR^{res} = (No. of response-stage background alarms)/(arbitrary constant).

Note that the quantities P_d^{res}, P_{fp}^{res}, P_{ba}^{res}, and BAR^{res} are functions of t^{res}, the threshold applied to the response-stage signal strength. These quantities can therefore be written as $P_d^{res}(t^{res})$, $P_{fp}^{res}(t^{res})$, $P_{ba}^{res}(t^{res})$, and $BAR^{res}(t^{res})$.

DISCRIMINATION STAGE DEFINITIONS

Discrimination: The application of a signal processing algorithm or human judgment to response-stage data that discriminates ordnance from clutter. Discrimination should identify anomalies that the demonstrator has high confidence correspond to ordnance, as well as those that the demonstrator has high confidence correspond to non-ordnance or background returns. The former should be ranked with highest priority and the latter with lowest.

Discrimination Stage Probability of Detection (P_d^{disc}): P_d^{disc} = (No. of discrimination-stage detections)/(No. of emplaced ordnance in the test site).

Discrimination Stage False Positive (fp^{disc}): An anomaly location that is within R_{halo} of an emplaced clutter item.

Discrimination Stage Probability of False Positive (P_{fp}^{disc}): P_{fp}^{disc} = (No. of discrimination stage false positives)/(No. of emplaced clutter items).

Discrimination Stage Background Alarm (ba^{disc}): An anomaly in a blind grid cell that contains neither emplaced ordnance nor an emplaced clutter item. An anomaly location in the open field or scenarios that is outside R_{halo} of any emplaced ordnance or emplaced clutter item.

Discrimination Stage Probability of Background Alarm (P_{ba}^{disc}): P_{ba}^{disc} = (No. of discrimination-stage background alarms)/(No. of empty grid locations).

Discrimination Stage Background Alarm Rate (BAR^{disc}): BAR^{disc} = (No. of discrimination-stage background alarms)/(arbitrary constant).

Note that the quantities P_d^{disc}, P_{fp}^{disc}, P_{ba}^{disc}, and BAR^{disc} are functions of t^{disc}, the threshold applied to the discrimination-stage signal strength. These quantities can therefore be written as $P_d^{disc}(t^{disc})$, $P_{fp}^{disc}(t^{disc})$, $P_{ba}^{disc}(t^{disc})$, and $BAR^{disc}(t^{disc})$.

RECEIVER-OPERATING CHARACERISTIC (ROC) CURVES

ROC curves at both the response and discrimination stages can be constructed based on the above definitions. The ROC curves plot the relationship between P_d versus P_{fp} and P_d versus BAR or P_{ba} as the threshold applied to the signal strength is varied from its minimum (t_{min}) to its maximum (t_{max}) value.[1] Figure A-1 shows how P_d versus P_{fp} and P_d versus BAR are combined into ROC curves. Note that the "res" and "disc" superscripts have been suppressed from all the variables for clarity.

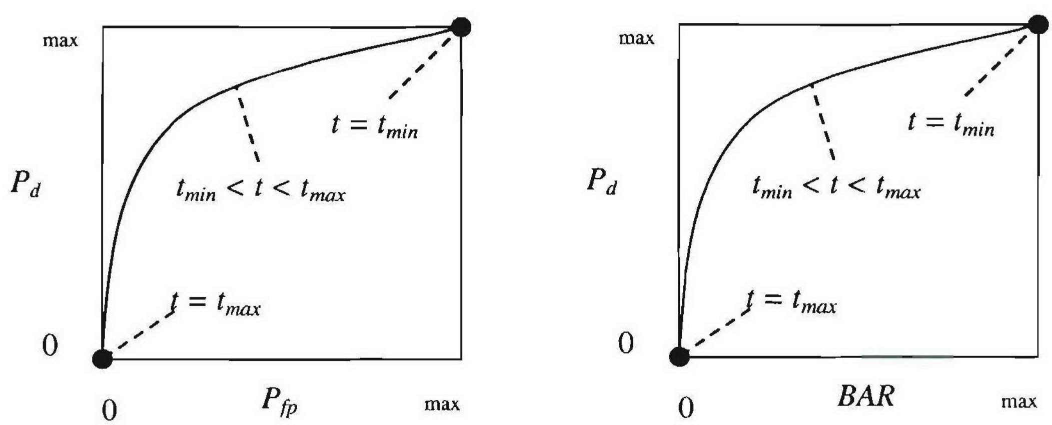

Figure A-1. ROC curves for open field testing. Each curve applies to both the response and discrimination stages.

[1]Strictly speaking, ROC curves plot the P_d versus P_{ba} over a pre-determined and fixed number of detection opportunities (some of the opportunities are located over ordnance and others are located over clutter or blank spots). In an open field scenario, each system suppresses its signal strength reports until some bare-minimum signal response is received by the system. Consequently, the open field ROC curves do not have information from low signal-output locations, and, furthermore, different contractors report their signals over a different set of locations on the ground. These ROC curves are thus not true to the strict definition of ROC curves as defined in textbooks on detection theory. Note, however, that the ROC curves obtained in the Blind Grid test sites are true ROC curves.

METRICS TO CHARACTERIZE THE DISCRIMINATION STAGE

The demonstrator is also scored on efficiency and rejection ratio, which measure the effectiveness of the discrimination stage processing. The goal of discrimination is to retain the greatest number of ordnance detections from the anomaly list, while rejecting the maximum number of anomalies arising from non-ordnance items. The efficiency measures the amount of detected ordnance retained by the discrimination, while the rejection ratio measures the fraction of false alarms rejected. Both measures are defined relative to the entire response list, i.e., the maximum ordnance detectable by the sensor and its accompanying false positive rate or background alarm rate.

Efficiency (E): $E = P_d^{disc}(t^{disc})/P_d^{res}(t_{min}^{res})$; Measures (at a threshold of interest), the degree to which the maximum theoretical detection performance of the sensor system (as determined by the response stage tmin) is preserved after application of discrimination techniques. Efficiency is a number between 0 and 1. An efficiency of 1 implies that all of the ordnance initially detected in the response stage was retained at the specified threshold in the discrimination stage, t^{disc}.

False Positive Rejection Rate (R_{fp}): $R_{fp} = 1 - [P_{fp}^{disc}(t^{disc})/P_{fp}^{res}(t_{min}^{res})]$; Measures (at a threshold of interest), the degree to which the sensor system's false positive performance is improved over the maximum false positive performance (as determined by the response stage tmin). The rejection rate is a number between 0 and 1. A rejection rate of 1 implies that all emplaced clutter initially detected in the response stage were correctly rejected at the specified threshold in the discrimination stage.

Background Alarm Rejection Rate (R_{ba}):

Blind Grid: $R_{ba} = 1 - [P_{ba}^{disc}(t^{disc})/P_{ba}^{res}(t_{min}^{res})]$.
Open Field: $R_{ba} = 1 - [BAR^{disc}(t^{disc})/BAR^{res}(t_{min}^{res})]$).

Measures the degree to which the discrimination stage correctly rejects background alarms initially detected in the response stage. The rejection rate is a number between 0 and 1. A rejection rate of 1 implies that all background alarms initially detected in the response stage were rejected at the specified threshold in the discrimination stage.

CHI-SQUARE COMPARISON EXPLANATION:

The Chi-square test for differences in probabilities (or 2 x 2 contingency table) is used to analyze two samples drawn from two different populations to see if both populations have the same or different proportions of elements in a certain category. More specifically, two random samples are drawn, one from each population, to test the null hypothesis that the probability of event A (some specified event) is the same for both populations (ref 3).

A 2 x 2 contingency table is used in the Standardized UXO Technology Demonstration Site Program to determine if there is reason to believe that the proportion of ordnance correctly detected/discriminated by demonstrator X's system is significantly degraded by the more challenging terrain feature introduced. The test statistic of the 2 x 2 contingency table is the

Chi-square distribution with one degree of freedom. Since an association between the more challenging terrain feature and relatively degraded performance is sought, a one-sided test is performed. A significance level of 0.05 is chosen which sets a critical decision limit of 2.71 from the Chi-square distribution with one degree of freedom. It is a critical decision limit because if the test statistic calculated from the data exceeds this value, the two proportions tested will be considered significantly different. If the test statistic calculated from the data is less than this value, the two proportions tested will be considered not significantly different.

An exception must be applied when either a 0 or 100 percent success rate occurs in the sample data. The Chi-square test cannot be used in these instances. Instead, Fischer's test is used and the critical decision limit for one-sided tests is the chosen significance level, which in this case is 0.05. With Fischer's test, if the test statistic is less than the critical value, the proportions are considered to be significantly different.

Standardized UXO Technology Demonstration Site examples, where blind grid results are compared to those from the open field and open field results are compared to those from one of the scenarios, follow. It should be noted that a significant result does not prove a cause and effect relationship exists between the two populations of interest; however, it does serve as a tool to indicate that one data set has experienced a degradation in system performance at a large enough level than can be accounted for merely by chance or random variation. Note also that a result that is not significant indicates that there is not enough evidence to declare that anything more than chance or random variation within the same population is at work between the two data sets being compared.

Demonstrator X achieves the following overall results after surveying each of the three progressively more difficult areas using the same system (results indicate the number of ordnance detected divided by the number of ordnance emplaced):

	Blind Grid	Open Field	Moguls
P_d^{res}	100/100 = 1.0	8/10 = .80	20/33 = .61
P_d^{disc}	80/100 = 0.80	6/10 = .60	8/33 = .24

P_d^{res}: BLIND GRID versus OPEN FIELD. Using the example data above to compare probabilities of detection in the response stage, all 100 ordnance out of 100 emplaced ordnance items were detected in the blind grid while 8 ordnance out of 10 emplaced were detected in the open field. Fischer's test must be used since a 100 percent success rate occurs in the data. Fischer's test uses the four input values to calculate a test statistic of 0.0075 that is compared against the critical value of 0.05. Since the test statistic is less than the critical value, the smaller response stage detection rate (0.80) is considered to be significantly less at the 0.05 level of significance. While a significant result does not prove a cause and effect relationship exists between the change in survey area and degradation in performance, it does indicate that the detection ability of demonstrator X's system seems to have been degraded in the open field relative to results from the blind grid using the same system.

P_d^{disc}: BLIND GRID versus OPEN FIELD. Using the example data above to compare probabilities of detection in the discrimination stage, 80 out of 100 emplaced ordnance items were correctly discriminated as ordnance in blind grid testing while 6 ordnance out of 10 emplaced were correctly discriminated as such in open field-testing. Those four values are used to calculate a test statistic of 1.12. Since the test statistic is less than the critical value of 2.71, the two discrimination stage detection rates are considered to be not significantly different at the 0.05 level of significance.

P_d^{res}: OPEN FIELD versus MOGULS. Using the example data above to compare probabilities of detection in the response stage, 8 out of 10 and 20 out of 33 are used to calculate a test statistic of 0.56. Since the test statistic is less than the critical value of 2.71, the two response stage detection rates are considered to be not significantly different at the 0.05 level of significance.

P_d^{disc}: OPEN FIELD versus MOGULS. Using the example data above to compare probabilities of detection in the discrimination stage, 6 out of 10 and 8 out of 33 are used to calculate a test statistic of 2.98. Since the test statistic is greater than the critical value of 2.71, the smaller discrimination stage detection rate is considered to be significantly less at the 0.05 level of significance. While a significant result does not prove a cause and effect relationship exists between the change in survey area and degradation in performance, it does indicate that the ability of demonstrator X to correctly discriminate seems to have been degraded by the mogul terrain relative to results from the flat open field using the same system.

APPENDIX B. DAILY WEATHER LOGS

TABLE B-1. WEATHER LOG

Time	Average Temperature, °C	Average Precipitation, in.
	10/18/2004	
0700	17.7	0.00
0800	18.4	0.00
0900	21.0	0.00
1000	22.9	0.00
1100	24.3	0.00
1200	25.4	0.00
1300	25.7	0.00
1400	26.2	0.00
1500	26.2	0.00
1600	26.2	0.00
1700	25.9	0.00
	10/19/2004	
0700	NA	NA
0800	NA	NA
0900	NA	NA
1000	NA	NA
1100	NA	NA
1200	NA	NA
1300	NA	NA
1400	NA	NA
1500	NA	NA
1600	NA	NA
1700	NA	NA
	10/20/2004	
0700	18.2	0.00
0800	19.8	0.00
0900	22.4	0.00
1000	23.6	0.00
1100	25.0	0.00
1200	25.5	0.00
1300	26.3	0.00
1400	26.5	0.00
1500	25.8	0.00
1600	25.5	0.00
1700	23.9	0.00

APPENDIX C. SOIL MOISTURE

Date: 18 October 2004
Times: NA, 1300 hours

Probe Location	Layer, in.	AM Reading, %	PM Reading, %
Calibration Area	0 to 6	NA	1.6
	6 to 12	NA	2.2
	12 to 24	NA	3.7
	24 to 36	NA	3.6
	36 to 48	NA	4.1
Mogul Area	0 to 6	NA	1.6
	6 to 12	NA	2.1
	12 to 24	NA	3.4
	24 to 36	NA	3.9
	36 to 48	NA	4.0
Desert Extreme Area	0 to 6	NA	1.6
	6 to 12	NA	2.3
	12 to 24	NA	3.2
	24 to 36	NA	3.9
	36 to 48	NA	4.0

Date: 19 October 2004
Times: 0630 hours, 1300 hours

Probe Location	Layer, in.	AM Reading, %	PM Reading, %
Calibration Area	0 to 6	1.8	1.8
	6 to 12	2.2	2.2
	12 to 24	3.7	3.7
	24 to 36	3.6	3.6
	36 to 48	4.1	4.1
Mogul Area	0 to 6	1.6	1.6
	6 to 12	2.0	2.1
	12 to 24	3.6	3.4
	24 to 36	3.9	4.0
	36 to 48	4.0	4.0
Desert Extreme Area	0 to 6	1.7	1.6
	6 to 12	2.0	1.8
	12 to 24	3.4	3.2
	24 to 36	3.9	3.9
	36 to 48	4.1	4.0

Date: 20 October 2004
Times: 0645 hours, 1230 hours

Probe Location	Layer, in.	AM Reading, %	PM Reading, %
Calibration Area	0 to 6	1.8	1.8
	6 to 12	2.2	2.2
	12 to 24	3.7	3.7
	24 to 36	3.6	3.6
	36 to 48	4.1	4.1
Mogul Area	0 to 6	1.6	1.6
	6 to 12	2.0	2.0
	12 to 24	3.4	3.4
	24 to 36	3.9	3.9
	36 to 48	4.0	4.0
Desert Extreme Area	0 to 6	1.7	1.6
	6 to 12	2.0	1.8
	12 to 24	3.4	3.2
	24 to 36	3.9	3.9

APPENDIX D. DAILY ACTIVITY LOGS

Date	No. of People	Area Tested	Status Start Time	Status Stop Time	Duration, min	Operational Status	Operational Status - Comments	Track Method	Track Method=Other Explain	Pattern	Field Conditions	
10/18/2004	2	CALIBRATION LANES	1125	1419	174	SETUP/DAILY START/ STOP/CALIBRATION	SETUP/ MOBILIZATION	NA	NA	NA	SUNNY	WARM WINDY
10/18/2004	2	CALIBRATION LANES	1419	1445	26	COLLECT DATA	COLLECTED DATA BIDIRECTIONAL EAST TO WEST	GPS	NA	LINEAR	SUNNY	WARM WINDY
10/18/2004	2	BLIND TEST GRID	1445	1527	42	COLLECT DATA	COLLECTED DATA BIDIRECTIONAL SOUTH TO NORTH	GPS	NA	LINEAR	SUNNY	WARM WINDY
10/18/2004	2	BLIND TEST GRID	1527	1548	21	SETUP/DAILY START/ STOP/CALIBRATION	END OF DAILY OPERATIONS/ EQUIPMENT BREAKDOWN	NA	NA	NA	SUNNY	WARM WINDY
10/19/2004	2	OPEN FIELD	0600	0738	98	SETUP/DAILY START/ STOP/CALIBRATION	SETUP/ MOBILIZATION	NA	NA	NA	SUNNY	COOL
10/19/2004	2	OPEN FIELD	0738	0816	38	COLLECT DATA	COLLECTED DATA BIDIRECTIONAL WEST TO EAST OPEN FIELD	GPS	NA	LINEAR	SUNNY	COOL
10/19/2004	2	OPEN FIELD	0816	0818	2	BREAK/LUNCH	BREAK	NA	NA	NA	SUNNY	COOL
10/19/2004	2	OPEN FIELD	0818	0855	37	COLLECT DATA	COLLECTED DATA BIDIRECTIONAL WEST TO EAST OPEN FIELD	GPS	NA	LINEAR	SUNNY	COOL
10/19/2004	2	OPEN FIELD	0855	0900	5	DOWN TIME DUE TO EQUIPMENT FAILURE	GPS INTERMITTENT	NA	NA	NA	SUNNY	COOL
10/19/2004	2	OPEN FIELD	0900	0946	46	COLLECT DATA	COLLECTED DATA BIDIRECTIONAL WEST TO EAST OPEN FIELD	GPS	NA	LINEAR	SUNNY	WARM
10/19/2004	2	OPEN FIELD	0946	1115	89	DOWN TIME DUE TO EQUIPMENT/ MAINTENANCE/ CHECK	CHARGING BATTERIES	NA	NA	NA	SUNNY	WARM
10/19/2004	2	OPEN FIELD	1115	1130	15	DOWN TIME DUE TO EQUIPMENT/ MAINTENANCE/ CHECK	CHECKING DATA	NA	NA	NA	SUNNY	WARM

Note: Activities pertinent to this specific demonstration are indicated in highlighted text.

Date	No. of People	Area Tested	Status Start Time	Status Stop Time	Duration, min	Operational Status	Operational Status - Comments	Track Method	Track Method=Other Explain	Pattern	Field Conditions	
10/19/2004	2	OPEN FIELD	1130	1200	30	BREAK/LUNCH	LUNCH	NA	NA	NA	SUNNY	WARM
10/19/2004	2	OPEN FIELD	1200	1505	185	COLLECT DATA	COLLECTED DATA BIDIRECTIONAL WEST TO EAST OPEN FIELD	GPS	NA	LINEAR	SUNNY	WARM
10/19/2004	2	OPEN FIELD	1505	1525	20	SETUP/DAILY START/ STOP/CALIBRATION	END OF DAILY OPERATIONS/ EQUIPMENT BREAKDOWN	NA	NA	NA	SUNNY	WARM WINDY
10/20/2004	2	OPEN FIELD	0627	0728	61	SETUP/DAILY START/ STOP/CALIBRATION	SETUP/MOBILIZATION	NA	NA	NA	SUNNY	COOL
10/20/2004	2	OPEN FIELD	0728	0841	73	COLLECT DATA	COLLECTED DATA BIDIRECTIONAL WEST TO EAST OPEN FIELD	GPS	NA	LINEAR	SUNNY	COOL
10/20/2004	2	OPEN FIELD	0841	0846	5	BREAK/LUNCH	BREAK	NA	NA	NA	SUNNY	COOL
10/20/2004	2	OPEN FIELD	0846	1013	87	DOWN TIME DUE TO EQUIPMENT/ MAINTENANCE/ CHECK	CHECKING DATA	NA	NA	NA	SUNNY	COOL
10/20/2004	2	OPEN FIELD	1013	1040	27	COLLECT DATA	COLLECTED DATA BIDIRECTIONAL WEST TO EAST OPEN FIELD	GPS	NA	LINEAR	SUNNY	COOL
10/20/2004	2	OPEN FIELD	1040	1050	10	SETUP/DAILY START/ STOP/CALIBRATION	SETUP/MOBILIZATION	NA	NA	NA	SUNNY	COOL
10/20/2004	2	BLIND TEST GRID	1050	1115	25	COLLECT DATA	COLLECTED DATA BIDIRECTIONAL EAST TO WEST	GPS	NA	LINEAR	SUNNY	COOL
10/20/2004	2	BLIND TEST GRID	1115	1155	40	BREAK/LUNCH	LUNCH	NA	NA	NA	SUNNY	COOL
10/20/2004	2	BLIND TEST GRID	1155	1221	26	DOWN TIME DUE TO EQUIPMENT/ MAINTENANCE/ CHECK	CHECKING DATA	NA	NA	NA	SUNNY	COOL
10/20/2004	2	BLIND TEST GRID	1221	1414	113	DEMOBILIZATION	DEMOBILIZATION END OF TEST TURN IN DATA	NA	NA	NA	SUNNY	COOL

Note: Activities pertinent to this specific demonstration are indicated in highlighted text.

APPENDIX E. REFERENCES

1. Standardized UXO Technology Demonstration Site Handbook, DTC Project No. 8-CO-160-000-473, Report No. ATC-8349, March 2002.

2. Aberdeen Proving Ground Soil Survey Report, October 1998.

3. Data Summary, UXO Standardized Test Site: APG Soils Description, May 2002.

4. Yuma Proving Ground Soil Survey Report, May 2003.

5. Practical Nonparametric Statistics, W.J. Conover, John Wiley & Sons, 1980, pages 144 through 151.

APPENDIX F. ABBREVIATIONS

AEC	=	U.S. Army Environmental Center
APG	=	Aberdeen Proving Ground
ATC	=	U.S. Army Aberdeen Test Center
CEHNC	=	Corps of Engineers - Huntsville Center
COTS	=	commercial off-the-wall
CRADA	=	Cooperative Research and Development Agreement
EM	=	electromagnetic
ERDC	=	U.S. Army Corps of Engineers Engineering Research and Development Center
ESTCP	=	Environmental Security Technology Certification Program
EQT	=	Army Environmental Quality Technology Program
GPS	=	Global Positioning System
JPG	=	Jefferson Proving Ground
PDOP	=	Position Dilution of Precesssion
POC	=	point of contact
QA	=	quality assurance
QC	=	quality control
ROC	=	receiver-operating characteristic
RTK	=	real time kinematic
RTS	=	Robotic Total Station
SERDP	=	Strategic Environmental Research and Development Program
STOLS	=	Surface Towed Ordnance Location System
UTM	=	universal transverse mercator
UXO	=	unexploded ordnance
YPG	=	U.S. Army Yuma Proving Ground

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